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Renewable energy in Oman: Status and future prospects

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ABSTRACT

This paper attempts to review and discuss the status and future prospects of renewable energy in Oman. Renewable energy sources like solar, wind, hydro, geothermal, and biomass have been revised. The electricity shortages and the challenges to overcome the increase in electrical demands for the near future have been discussed. The investigations found that solar, shore-wind and geothermal could play an important role in the future of renewable energy in country. Also, it is found that there is need to investigate the potential of offshore-wind, biomass, and hydro (tide, wave and ocean thermal energy). The appearance and weight of renewable energy in the higher education programs and the Oman commitment toward renewable energy have been discussed. The paper finishes with some conclusions and recommendations.

Contents

1. Introduction

In this era of global warming, along with the increasing demand for energy and depletion of the fuel stocks (especially fossil fuels), non-renewable resources are being used at a prodigious and unsustainable rate. These resources will be gone at some time in the not-too-distant future.

Such a situation forces us to look for renewable energy resources. Peak electricity demand in Oman will increase from 2773 MW in 2007 to an expected 5691 MW in 2014. The annual growth rate, at approximately 17.8%, is high, and peak demand is envisaged to continue increasing due to the accelerated industrial and population growth in Oman. The electricity generation forecasting in 2014 will be 24.0 TWh, and electricity shortages are expected to occur in the near future if current trends continue. The production of natural gas in 2009 is 1,097,661 MNSCF as shown in Fig. 1a. The Omani government accounts for 29.16% of total gas production in 2008 (see Fig. 1b), while the remainder is used in oil-production and for export, and up to 92% of the natural gas is domestically used for producing electricity [1]. If we continue to build power stations which utilize gas for electricity production Oman will have to import, rather than export gas. All power generation facilities at present are dependent on nonrenewable fossil fuels; thus it is strongly advisable to seek alternative sources

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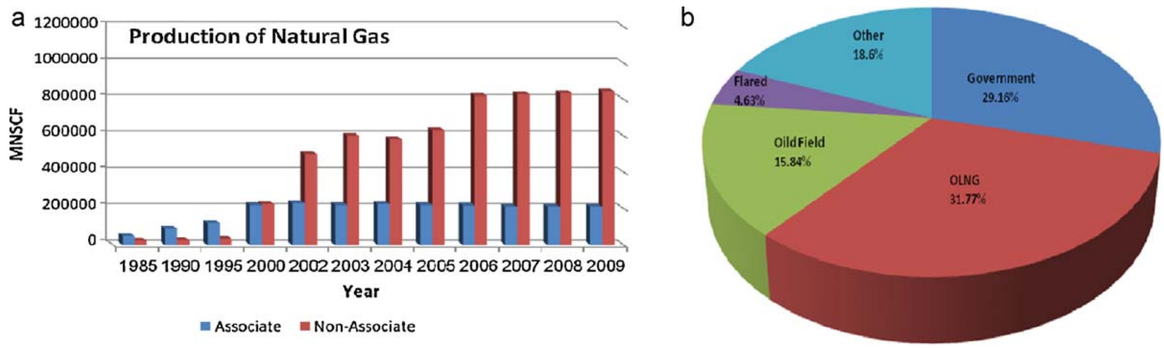


Fig. 1. (a) Production of natural gas and (b) usage of natural gas in 2008.

of energy. The three most important factors in selecting new energy sources are that they must be: renewable, locally available, and environmentally friendly. Oman is potentially one of the best regions for utilization of alternative sources of renewable energy such as solar, wind, hydro, and geothermal energies.

The present paper attempts to explore the statues and future prospects of renewable energy in Oman. An attempt has been made through this paper to review the availability of renewable energy options in industrial, electrical, and higher education sectors. Moreover, the potential of renewable energy sources have been revised. The aim is to promote the public awareness and inspire local government to dedicate more efforts and funds in the renewable energy utilization.

2. Key information of Oman

Oman has an area of 212,460 km^2 and a coastline that totals 2092 km^2 and its location in the Middle East, on the eastern edge of the Arabian Peninsula. The latitude and longitude of Oman is (21 00N, 57 00E). The climate is generally very hot, with temperatures reaching 48 °C in the hot season, from May to September. In addition, the climate of Oman remains dry (no rainfall) and extremely hot, but also is humid in the coastal region throughout most of the year [2–5].

The total population of Oman in 2010 is 3,174,000 including 1,156,000 expatriate. The country is divided into nine administrative districts: Muscat, Musandam, Dhofar, Al Buraimi, Al Batinah, Adh Dhahirah, Ad Dakhliyah, Ash Sharqiyah, and Al Wusta. The total number of housing in Oman is in the order of 540,770, includes individual houses and apartments in building. In 2010, the following sectors share in the Gross Domestic Product GDP reached (in million of Omai Rial OR): 7317.2 oil and gas, 258.6 agriculture and fishing, 3325.3 industrial activities, and 7519.0 service activities (0.386 OR ≈ 1 US$) [2].

2.1. Industry

In eighty decades the industrial development in Oman has usually focused on relatively small scale manufacturing. With the discovery in the early 1990s of large deposits of non-associated natural gas, the focus of government efforts has shifted to attract large investment in capital-intensive gas-based industries. Accordingly, five main industrial estates have been established. Manufacturing industry has generally been located on the country's industrial estates; Raysut, Sohar, Nizwa, Sur and Buraimi industrial estates.

In the late 1980s and early 1990s the discovery of natural gas paved the way for development of gas-based industry in the country. Gas-based industrial development is central to the country diversification plans. Much of it will be based in Sohar, where there is a new industrial port with dedicated container-handling facilities, and gas is supplied by pipeline from central Omani fields. Also, the Oman Refinery Company (ORC) which was established in 1982 with the aim of serving the local market. The refinery, which is in Muscat, currently has a processing capacity of more than 106,000 b/d (late 2006).

2.2. Electricity

Electricity companies former structures constructed from the following government owned companies:

Electricity Holding, Oman Power and Water Procurement, Oman Electricity Transmission, Wadi Al Jizzi Power, Al Ghubrah Power and Desalination, Mazoon Electricity, Majan Electricity, Muscat Electricity Distribution, and Rural Areas Electricity Companies.

Market structure sector comprises three separate and distinct markets: Main Interconnected System (MIS), the Rural Systems (RAECO) and the Salalah Power System. MIS Electricity Demand Forecast peak demand will increase from 2773 MW in 2007 to an expected 4634 MW in 2013 as shown in Fig. 2 [1,2,6]. All the mean power generation is dependent on fossil fuel; this is unadvisable to depend on one type of energy source. In addition to that, the fossil fuel is nonrenewable.

2.3. Higher education

Higher education system in Oman is relatively young [7]. The first public university in Oman, Sultan Qaboos University SQU was founded in 1986 [8]. In addition, there is Technical Colleges TC and Colleges of Applied Science AS. In 2001 Sohar University SU the first private university was founded [9]. Later on some private universities and colleges have been established. Engineers are developing our products and projects of our application of today technology. For that engineering education is related directly to the renewable

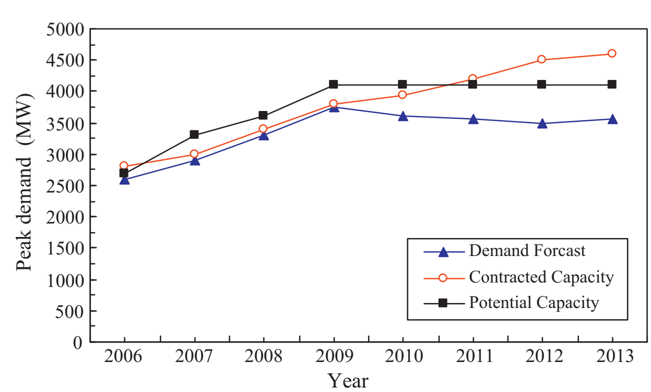


Fig. 2. Projection of the peak demand in Oman till 2013.

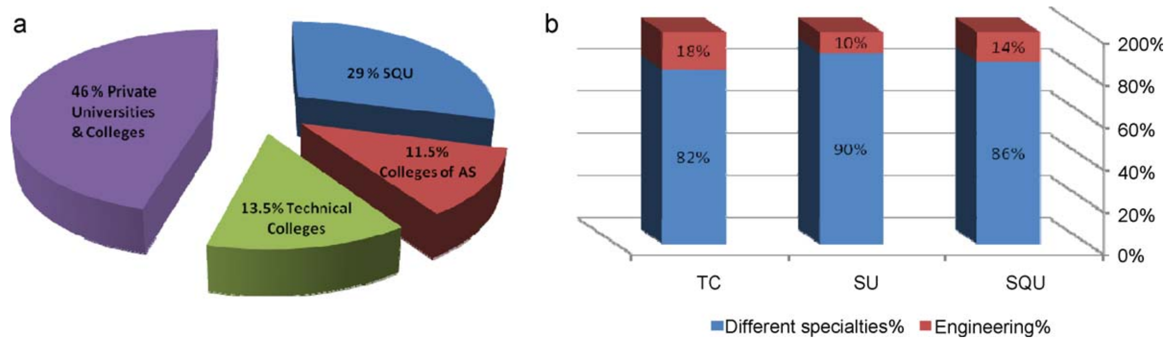


Fig. 3. (a) Percentage of total students in different universities and colleges and (b) percentage of engineering students in different universities and colleges.

energy. Fig. 3 shows statistics of engineering education in Oman (Public and Private). It is clear seen that engineering students are less than 20% in SQU, SU and TC [2].

Also, faculties of engineering in higher education institutions in Oman public and private contain different specialties as shown in Tables 1 and 2 respectively. In these programs it is found that renewable energy present only in two courses, one in Dhofar and one in Sohar universities. These courses represent 3% of the Bachelor program. Also, there are two renewable energy research groups one in SQU and another in SU.

3. Renewable energy in Oman

It is good to start this section by the following question: Why renewable energy for Oman? The answer for this question not only because of the expected shortage in electricity in the future but also because of: rising prices of Oils and Gases, ample resources and sites available, ecological hazards, government incentive, abundant sunshine, and increased financing options. In the next sub-sections we will provide an overview of potential renewable energy in Oman, and the potential use of such resources for electricity production.

3.1. Solar energy

Oman has one of the highest solar densities in the world. According to the Authority for Electricity Regulation in Oman, "Oman and solar energy has the potential to provide sufficient electricity to meet all of Oman's domestic electricity requirements and provide some electricity for export" [1]. Humidity and dust plus the lack of rainfall are barriers to using PV [2–4,10]. Areas of highest solar density are the desert areas; the coastal areas in the southern part of Oman have the lowest solar density [11].

A. Photovoltaic (PV) systems
- The solar PV technology is suitable for use in northern parts of Oman for producing electricity.
- The solar PV technology is also suitable for electricity generation in off-grid power plants in rural desert areas where the solar energy can reduce diesel fuel use.
- The efficiency of PV cells is influenced by high air temperature and dust contamination.

B. Solar thermal plant
- Concentration solar power CSP expected to be very well suited to the conditions in Oman, where the long shining day and high temperature.
- Steps are in place in Oman to develop the first large scale solar power plant locally whose capacity will range between 50 and 200 MW.

Implementations of PV or CSP systems have shown that their reliability and efficiency depend on many factors, the dominant being location (latitude, longitude, and solar intensity), environmental (temperature, wind, humidity, pollution, dust, rain, etc.) and the type of PV used. Thus before committing to a large PV or CSP project, a thorough investigation of the above factors is essential.

3.2. Wind energy

A. Shore
- It is found that there is significant wind energy potential in coastal areas in the southern part of Oman and in north of Salalah on the mountains.

B. Offshore
- There is a lot of wind energy available offshore. If we take in consideration that Oman has a coastline of almost 1700 km, from the Strait of Hormuz in the north to the borders of the Republic of Yemen in the south-west, overlooking three seas: the Arab Gulf, the Gulf of Oman and the Arabian Sea, than there is a huge amount of wind energy offshore in Oman.
- Little studies have been done to specify offshore wind energy in Oman in the last 20 years.

3.3. Hydro energy

Hydropower is the energy that comes from the normal flow of water. Oman have a long coast and taken in consideration that most of the cities and population living near the coast.

A. Tide energy
- Tides are caused through a combination of forces created by the gravitational pull of the sun and the moon, and the rotation of the earth. No studies have been done to specify the potential of tide energy in Oman.

B. Wave energy:
- Using the kinetic (dynamic) energy of the waves to rotate an underwater power turbine and generate electricity. There has been some scientific study of internal waves in the Arabian Sea and Gulf of Oman through the use of satellite imagery. The imagery shows evidence of fine scale internal wave signatures along the continental shelf around the entire region.
- More studies need to be carried to specify the potential of wave energy in the country.

C. Ocean thermal energy converter OTEC
- OTEC is the using of the thermal energy of oceans to generate electricity. This type of energy is depending on the depth of the ocean. The maximum depth of the Arabian Sea is approximately 4652 m. Because of the depth of Arab Sea and Gulf of Oman we expect that there is possibility to find feasible OTEC energy in Oman.

Table 1
Higher Education Institutions-Oman, Public HEI-Engineering.

Institute/Program Sultan Qaboos University	Institute/Program Technical Colleges	Institute/Program College of Applied Science
Civil Eng	Computer Eng	Electrical Eng
Mechanical Eng	Electrical and Power Eng	Architecture Eng
Electrical and Computer Eng	Mechanical and Industrial Eng	Chemical Eng
Mechanical Eng	Quality Surveying Eng	
Industrial Eng		
Petroleum and Gas Eng		
Chemical Eng		
Mechatronic Eng		

- On our best knowledge NO studies in the last 20 years have been carried to investigate OTEC near the coast of Oman.

3.4. *Geothermal energy*

Geothermal energy is available as heat emitted from within the earth's crust, usually in the form of hot water or steam. It is exploited for electricity generation using dry steam or high enthalpy brine after flashing, or directly as heat for district heating, agriculture, etc. There are more than 55 bore holes in Oman (Fig. 4), where the water temperature in the range of 68–137 °C.

3.5. *Biomass energy*

The interest in using biomass as an energy source has increased and estimated to reach 15–50% of world primary energy by 2050 [12]. The situation of potential biomass could be summarized as follows:



Fig. 4. Area with boreholes with temperature above 100 °C.

- The Oman biomass sector has the potential to expand without harmful effects on food supplies and the environment if done in a sustainable manner.
- Greater recovery of wood from unmanaged and managed woodland could make a significant contribution to Oman energy targets.
- There is No industry of biofuels in Oman. However, there is good potential for the Oman to expand its production of sustainable biofuel in the future.
- In the literature, the number of publications dealing with biomass energy resource in Oman is limited.

4. Oman commitment toward renewable energy

There is increase interest and support for the Oman government toward use and invest in renewable energy. The government's was firm commitment to the continued development of the country's human resources. As a step forward The Oman Research Council start work to fund research projects in different sectors. The areas of research are grouped into six major sectors that constitute the main dimensions of economic and social development in the Sultanate. The grants for research are managed by Research Grant Committees—one by sector. One and may be the important is "Industrial and Energy Sector". SQU and SU have won some of these grants in the area of energy.

Also, country government and power companies in Oman work together with outer power companies that work in renewable resources to generate electricity. The results of their excellent studies about solar energy in Oman found that country has the ability and properties to establish solar energy systems. Elaborating on the findings of a feasibility study conducted by the Public Authority for Electricity and Water (PAEW) in December 2009, the study found that a large scale, commercial solar power project is feasible in the country. However, the performance parameters of potential PV system in Oman such as longitude, latitude, incident angle, air mass, module temperature, cell temperature, voltage, current,

Table 2
Higher Education Institutions, Private HEI-Engineering.

Institute/Prog. Nizwa University	Institute/Prog. Sohar University	Institute/Prog. Dhofar University	Institute/Prog. Caledonian College of Engineering	Institute/Prog. Al Sharq Al-Awsat College
Electrical Eng.	Electrical and Computer Eng	Electrical and Computer Eng	Electronic Eng	Electronics and Communications
Computer Eng.	Chemical and Mechatronic Eng	Mechanical Eng	Computer Aided Mechanical Eng	
Civil Eng	Chemical Eng	Chemical Eng	Telecommunication Eng	
Internal Decoration Eng	Civil Eng	Graphic Design and Interior Architecture	Computer Eng	
Architecture Eng			Mechatronics	
Chemical and Petrochemicals Eng			Process Operation and Maintenance	
Environmental Eng			Electrical Power Eng	
			Chemical Eng	
			Civil Eng	
			Construction Eng	

power, efficiency, and pollution have not been investigated on their study.

Moreover, the Authority for Electricity Regulation in Oman has confirmed a shortlist of six renewable energy pilot projects. Two projects for immediate implementation and they are 100 kW PV solar projects and other one is 500 kW wind project. These projects will reduce carbon dioxide emissions and protect the environment.

5. Conclusions and recommendations

Oman major achievements and author recommendations on renewable energy development can be summarized as follows:

Electricity and Industry:

1. It is found that solar energy density in Oman is among the highest in the world. Also, there is significant shore-wind energy potential in coastal areas in the southern part of Oman and in the mountains north of Salalah.
2. The potential for utilizing geothermal energy for electricity production is found to be limited in comparison with solar and shore-wind energy but still feasible.
3. The potential use of wave energy is considered marginal compared to solar and wind energy resources.
4. More studies need to be carried to investigate offshore wind, geothermal, tide, wave, and OTEC energy.
5. Support and implement small renewable energy pilot projects specially that serve people in rural areas.
6. Financial support for studies that lead to investigate renewable energy in Oman and their applications.
7. Introducing solar thermal collectors in public buildings to produce hot tap water.

Higher Education:

1. Graduates M.Sc. program in renewable energy science will serve as workforce and catalysts in promoting increased use of renewable energies in a world that is gradually moving toward a more conscious and sustainable use of energy sources.
2. Encourages and sponsor 4th year projects in renewable energy.
3. There is a need to establish guidelines and standards regarding academic programs and to establish a system of accreditation, preferably global, of RE in different academic discipline.

References

[1] Authority for Electricity Regulation in Oman. Study on renewable resources. Oman: Final Report; May 2008. p. 14.
[2] Ministry of National Economy. Statistical Yearbook. November; 2010.
[3] Ministry of Oil & Gas, letter dated 13 February 2008. Ref. 478.
[4] Oman Power and Water Procurement. Annual Report; 2006.
[5] Oman Power and Water procurement. Seven Years Statement; 2007–2013.
[6] Al-Badi AH, Malik A, Gastle A. Assessment of renewable energy resources potential in Oman and identification of barrier to their significant utilization. Renewable and Sustainable Energy Reviews 2009;13: 2734–9.
[7] Ministry of Higher Education. http://www.mohe.gov.om.
[8] Sultan Qaboos University. http://www.squ.edu.om.
[9] Sohar University. http://www.soharuni.edu.om.
[10] Chung Yu T, Shiuan Chien T. Analysis and simulation of characteristics and maximum power point tracking for photovoltaic systems. In: International Conference on Power Electronics and Drive Systems. 2009. p. 1339–44.
[11] Photon International. October; 2010.
[12] Kumar A, Kumar K, Kaushik N, Sharma S, Mishra S. Renewable energy in India: current status and future potentials. Renewable and Sustainable Energy Reviews 2010;14:2434–42.